Strategic Review of Heavy-Duty Engine Emission Regulations and Alternate Fuels

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Reviewed in this paper are the heavy-duty diesel engine emission standards and related issues that will determine the engine technology available in the marketplace in the future. The concerns identified need to be discussed and resolved in the light of what the industry and government agree to accomplish in the years ahead. This involves such major issues as U.S. energy and environmental policy. Alternate fuels could play a role in meeting the tougher environmental standards and in reducing U.S. dependence on imported petroleum. However, this may happen only if industry is given better information and direction on which to base the business decisions that will ultimately result in the commercial development of alternate fuel technology.

The future emission regulations facing the heavy-duty diesel engine industry generate concerns about the technology and business strategies that will result in viable production plans for the future. Although these regulations are firm, there are questions remaining about the availability of technology and details, such as nonconformance penalties, that need to be known before optimal choice can be made. This makes it difficult, if not impossible, to develop strategies that an organization can use for developing products that will meet the regulations, satisfy the customer, and make a profit. These uncertainties affect not only the engine manufacturer, they also affect the customers who will ultimately have to deal with the new equipment and meet the challenges posed by tougher regulations.

This paper is based on a presentation to the American Gas Association meeting, On the Road with Natural Gas, held in Indianapolis, Indiana, in September 1987. The purpose of the presentation was to point out that even though alternate fuels may satisfy the tougher emission standards, there is no guarantee that a viable business strategy can be developed to move these fuels into the marketplace. Until the U.S. government can provide a more definitive energy policy, the windows of opportunity for alternate fuel technology may not be as "open" as might be desired. Industry will require long-term guarantees that new technologies can be sold and provide a return on the investment, or adopting these technologies will prove to be a poor business decision and they will never be brought to production.

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Although many questions remain, Detroit Diesel has made the decision to develop methanol engine technology for the 1991 urban bus market. However, depending on decisions made by the U.S. government on energy policy and long-term emission regulations, a negative business decision may still keep the engine out of the marketplace.

HEAVY-DUTY DIESEL ENGINE EMISSION REGULATIONS

Table 1 gives the current heavy-duty diesel engine (HDDE) emission standards. The purpose of this EPA regulatory program is to encourage manufacturers to build durable emission control systems that comply with the prescribed standards. This program increases recall liability, extends durability testing for system deterioration rates, and affects design targets. These standards pertain to engines tested on the federal transient emission test (TET) on an electric dynamometer. Details of the test and regulations are available in the *Code of Federal Regulations* (*1*). This table is constructed to show changes that will occur by calendar year. Therefore, only the emission standards that change are shown. For example, the hydrocarbon (HC) and carbon monoxide (CO) standards remain at 1.3 and 15.5 g/bhp-hr, respectively, for the entire period and are only listed in calendar year 1987.

TABLE 1 U.S. HEAVY-DUTY DIESEL EMISSION STANDARDS

Model Year	Regulated Pollutant	Standard (g/bhp-hr)	Approximate Design Target (g/bhp-hr)
1987	HC	1.3	1.2
	CO	15.5	15.3
	NO_x	10.7	10.2
1988	Particulates	0.60	0.5
1990	NO_x	6.0	5.0
1991	NO_x	5.0	4.5
	Particulates		
	Trucks	0.25	0.16
	Buses	0.10	0.05
1994	Particulates	0.10	0.05

The design targets in the last column represent the estimated level of individual emissions required for the engines to be capable of passing an end-of-line audit and a field audit. End-of-line audits must take into consideration the variabilities in new engine builds as well as measurement variabilities. The Environmental Protection Agency (EPA) reserves the right to request production line audits that, if not passed, can cause the production line to be shut down until the manufacturer proves that the production engines meet the standard. Because of the statistical nature of these data, a target mean engine emission value ($\overline{X}$) that is lower than the standard is necessary.

The field audit mileages for the different diesel engine classifications are given in Table 2. The certification/recall mileage, or full useful life of the engine, shows the length of service during which field recalls can be made and engines are required to meet the standard. The surveillance mileage is the planned field audit mileage. Minor hardware changes can occur with use, and it is the responsibility of the manufacturer to determine the magnitude of any potential emission deterioration resulting from these changes over the full useful life of the engine in service. Because this would require years of field testing, a shorter dynamometer durability test is run in the laboratory and extrapolated to the hours associated with the full useful life in the field. The deterioration factor (DF) must then be subtracted from the mean production engine emission level to establish the design target. This can be expressed by a simple equation:

$$\overline{X} = (A - DF)/KS$$

where

$\overline{X}$ = population mean;
A = emission standard;
DF = deterioration factor;
S = standard deviation; and
K = a factor related to the sample size, confidence level, and other statistical information.

TABLE 2 REGULATORY PROVISIONS (full useful life)

Vehicle Classification	Certification/ Recall (mi)	Surveillance (mi)
Light-duty trucks	120,000	90,000
Light heavy-duty engines	110,000	82,500
Medium heavy-duty engines	185,000	138,750
Heavy heavy-duty engines	290,000	217,500

Beginning in 1988 (Table 1), the HDDE will have to meet a particulate emission standard measured on the TET. The value will be 0.6 g/bhp-hr. In 1990 the HC, CO, and particulate standards will remain fixed, but the nitrous oxide (NO_x) standard will drop from 10.7 to 6.0 g/bhp-hr.

In calendar year 1991, both NO_x and particulate standards will be reduced. The NO_x standard will drop from 6.0 to 5.0 g/bhp-hr. Particulate reductions will differ for two categories of HDDEs, urban buses and all other HDDE applications. Urban buses, as defined in the *Code of Federal Regulations* (*1*), must meet a 0.1 g/bhp-hr standard, and all other engines must meet a 0.25 g/bhp-hr standard. In 1994 all HDDEs must meet the more stringent 0.1 g/bhp-hr particulate standard.

In the following discussion of business and emission technology strategies, the period through 1990 is referred to as the near term, 1991 through 1993 as the midterm, and 1994 and beyond as the far term.

NEAR-TERM CONSIDERATIONS

In the near term known technologies can be used to meet the new emission standards for HDDEs. These technologies include various combinations of aftercooling, injection timing control, air-fuel ratio control, and improved combustion systems. Engines that have not been developed to meet these emission standards will most likely be dropped from production because the standards will be getting tougher and high-emission engines will not be marketable in the future. In the midterm all HDDE applications, excluding urban buses that fall into Category 2, will be important.

MIDTERM CONSIDERATIONS

Category 1

The HC and CO standards remain unchanged, but the NO_x standard drops from 6.0 to 5.0 g/bhp-hr. Because of prior experience with the 5.0-g NO_x standard in California, the technology necessary for this reduction is already in use. The particulate standard is also reduced from 0.60 to 0.25 g/bhp-hr, which creates a new challenge. Development to date suggests that state-of-the-art engines with air-to-air charge cooling, high-pressure electronically controlled injection systems, excellent engine oil control, and low-sulfur fuel will be able to achieve the design targets necessary to certify and sell these engines in the midterm.

There are three options for production engines that cannot be modified economically to meet this new standard:

1. Apply aftertreatment devices to reduce particulates,
2. Pay nonconformance penalties, and
3. Burn alternate fuels that can reduce both NO_x and particulates.

Option 1 does not appear feasible because no commercial aftertreatments devices are available today, and it would require a significant effort to have them available by 1991 even if the technology were well defined today, which it is not. However, it is possible that aftertreatment could become commercially available before the end of the midterm.

Option 2, pay a nonfonformance penalty (NCP), can probably be exercised only for a year or possibly two because of the escalating penalties that are typically assigned. The NCP concept is explained in the *Code of Federal Regulations* (*1*). Unfortunately, the details of the particulate NCPs are as yet unknown, which makes it difficult to develop a business strategy including this option.

Option 3 would require developing an alternate fuel strategy for a wide variety of HDDE applications. This will be difficult if any commercial engines are capable of meeting the midterm standards without aftertreatment or NCPs.

Given current fuel prices, present environmental regulation alone does not guarantee a profitable market for heavy-duty engines using alternative fuels. The market is more likely to be "opened" for alternative fuels primarily on the basis of fuel prices, not environmental regulation. Because future fuel prices are so uncertain, industry cannot afford the risk of developing alternative-fueled engines without some form of guarantee of an ongoing market for these engines.

Given the likelihood that some engines will meet the midterm standards, all engines in this category must meet the standards without resort to any of the three options or they will be noncompetitive. The exception could be the older production engine that could survive in the marketplace if the manufacturer paid a minimal NCP for a year or two. This can only be determined for sure when the details of NCP for particulates are made available and examined as a potential business strategy.

Category 2

The second category of importance in the midterm is the urban bus. All emissions standards are the same as for Category 1 except that the particulates standard is much lower, 0.1 g/bhp-hr. Attaining this particulate level does not appear to be possible without aftertreatment. The same three options are available. Because it is believed that commercial aftertreatment devices will not be available until possibly late in the midterm, aftertreatment devices can be only part of a viable business strategy. NCPs are expected to start at a level approximately equivalent to the cost of technology to meet the standard in 1991, and therefore paying NCPs could be a viable business option for the first year of the midterm. However, an acceptable business strategy would also depend on the introduction of commercial aftertreatment devices in 1992 or 1993 to allow the engine to continue to be sold competitively. If that did not happen, the NCPs could prove to be a competitive disadvantage in 1992 and would certainly be a disadvantage in 1993, leading to dropping such engines from the product plan.

The third option, using alternate fuels in the urban bus market, provides a potential advantage over the options available for diesel-fueled engines. As will be shown later, the Detroit Diesel methanol bus engine can now meet the midterm emission standards for urban buses. If this engine can be shown to meet all of the other customer criteria by 1990, it can be a viable commercial candidate for this market. Obviously, there are other issues and technology strategy decisions that must be considered.

FAR-TERM CONSIDERATIONS

In the far term all HDDEs must meet the lower particulate standard of 0.1 g/bhp-hr. Assuming no commercial diesel fuel–burning engines that reach this particulate level can be developed by that time, the same three options are available. It is certainly possible that a commercial aftertreatment device could be available by 1994 or earlier. If this happens, the only reason to consider Option 2 would be that a life-cycle cost analysis of engines sold in 1994 and succeeding years showed some advantage to paying NCPs. Because details of the NCP are not available for analysis, this option is unclear at this time. However, if the rationale for NCPs is properly applied, this should not prove to be a good business decision, certainly not after 1994, the first year of the introduction of the tougher standards for all HDDEs.

However, even engines that produce 0.25 g/bhp-hr will require 80 percent efficient traps to reach the 1994 design target of 0.05 g/bhp-hr. Engines that meet the 1991 design target of 0.16 g/bhp-hr could reach the 1994 design target with a 35 percent efficient aftertreatment device. This becomes important because completely different aftertreatment technologies could be developed depending on the efficiency required. If high-efficiency traps are not available, higher particulate emitting engines would not be capable of meeting the standard.

Another possibility that must be considered is that trap technology may not prove to be commercially viable by 1994—for reasons of economics or durability. This leads to the possibility that diesel-burning engines could become very expensive as NCPs rise. Obviously, the federal government could act to delay or change the standards rather than legislate diesel engines out of the marketplace by causing them to be at an economic disadvantage. However, if engines burning alternate fuels can achieve these standards, the government could force the industry to switch fuels to achieve the environmental objectives for which these standards were developed.

MIDTERM IMPLICATIONS OF TRAP DEVELOPMENT

If aftertreatment becomes available in 1994 or before, there is a business concern in developing alternate fuel engines for urban bus use for the midterm. The development costs of such an effort must be offset by future product sales.

In the worst-case scenario, it can be assumed that the diesel engine could be sold in the urban bus market with NCPs in 1991 and that aftertreatment devices would become available in 1993. This suggests alternate fuel engine sales would be viable for only 1 year, involving the sale of only a few thousand engines, before diesel-fueled engines again would become a competitive product. One year of sales would not be adequate to justify a positive business decision for alternate fuels on the part of either the engine manufacturer or the transit authorities. This leads to questions about the interrelationship of U.S. policies on environment and energy. If the United States is to reduce its dependence on petroleum-based fuels, a decision must be made soon that will lead to the introduction of an alternate fuel into the U.S. commercial marketplace. Methanol is currently the fuel of choice, and the environmental issues could provide the means of introducing it.

A review of the emission standard scenarios suggests that, in limited market segments, the emission standards could be used to encourage the use of alternate fuels while improving the environment. For example, if the NO_x standard were reduced in the far term for the urban bus, the possibility of meeting the lower standard with diesel fuel would be diminished. An NO_x level of 2.5 g/bhp-hr might be a feasible value for consideration. This would ensure a market for the alternate fuel for a sufficient period of time to encourage engine manufacturers to make the business and technology development decisions necessary to bring these engines to the marketplace. It would also require transit authorities to seriously consider the numerous decisions that must be made if alternate fuels are to be used. Obviously, there are a number of other technology-forcing scenarios that could be brought to bear on this dilemma by various government agencies.

SUMMARY

The future emission standards are not only presenting new technical challenges, they are also raising difficult business concerns. As long as the needed technology for the basic engine, and especially particulate traps, is uncertain and the necessary information about NCPs is unavailable, both technology and business strategies are difficult if not impossible to formulate with any confidence.

For example, strategies for meeting the midterm urban bus emission standards include the possibility of using alternate fuel technology, but uncertainty about future sales of such products has complicated the business decision to proceed with this development. As has been discussed, the possibility of using NCPs and the uncertainty about the availability of commercial particulate traps during the midterm do not support the investment necessary for alternate fuel development. What needs to be done is to guarantee future sales of alternate fuel technology in the United States by supporting it either as part of a U.S. energy policy or as a means of providing a cleaner environment. A lower NO_x standard for selected applications, such as the urban bus in the far term, could provide an ongoing market for alternate fuel technology.

Detroit Diesel has decided to proceed with development of the 6V-92TA methanol engine for commercial applications in 1991. This decision is based on involvement in the bus market, the competition, the potential for meeting the difficult urban bus emission standards with this technology, and the belief that both U.S. energy and environmental policies should support this decision in the future. Obviously, information is still lacking, but technology development is proceeding while all of the alternatives are reviewed.

DETROIT DIESEL'S METHANOL ENGINE

Detroit Diesel selected methanol as the most likely alternative to petroleum-based fuels should another energy crisis occur. Since that decision, which was the result of a General Motors Corporation study of alternative fuels, many others have adopted this fuel for similar reasons. However, in the last few years the availability of petroleum and its price have led to the selection of methanol for another reason—its ability to produce low emissions and improve the quality of the environment.

In the early 1980s, Detroit Diesel developed a 6V-92TA methanol-burning two-stroke engine that appeared to have a commercial advantage over other methanol engine configurations. Because the two-stroke engine is the market leader in transit bus sales in the United States and most of North America, it became a natural contender to satisfy the midterm emission standards for urban buses.

The engine modifications necessary for operation on methanol are shown in Figure 1. Descriptions of this engine, the urban bus installation, and vehicle performance in revenue service are given elsewhere (2–4). For several years engine development was curtailed by the depressed economic state of the HDDE business. However, in an agreement reached with the EPA, several consumer groups, and General Motors, the opportunity was provided to continue the development of the two stroke methanol engine. Results from the initial year of effort have been quite encouraging, as shown by the modified engine test results given in Table 3 and shown in Figures 2–4. The emission data in Table 3 indicate that the modified engine easily meets the NO_x and CO standards for the 1991 urban bus and, therefore, the 1994 standards for all HDDEs. Currently, the HC TET results are above the 1.3 g/bhp-hr standard. The most recent weighted hot-cold cycle numbers are approaching the standard, but more improvement is necessary. The particulate emissions of the modified engine are already near the design target level of 0.05 g/bhp-hr. All of these emission levels were achieved without any exhaust aftertreatment device.

Although currently there is no aldeyhde standard, the EPA agreement identified an aldeyhde goal of 0.1 g/bhp-hr for this development program. To date, aldehyde levels of between 0.3 and 0.4 g/bhp-hr on the TET have been achieved without aftertreatment, but, unfortunately, all catalyst systems tested to date have increased the aldehyde levels rather than decreased them on the TET. The effort to identify and select an appropriate catalyst continues, but it must be paralleled by a similar

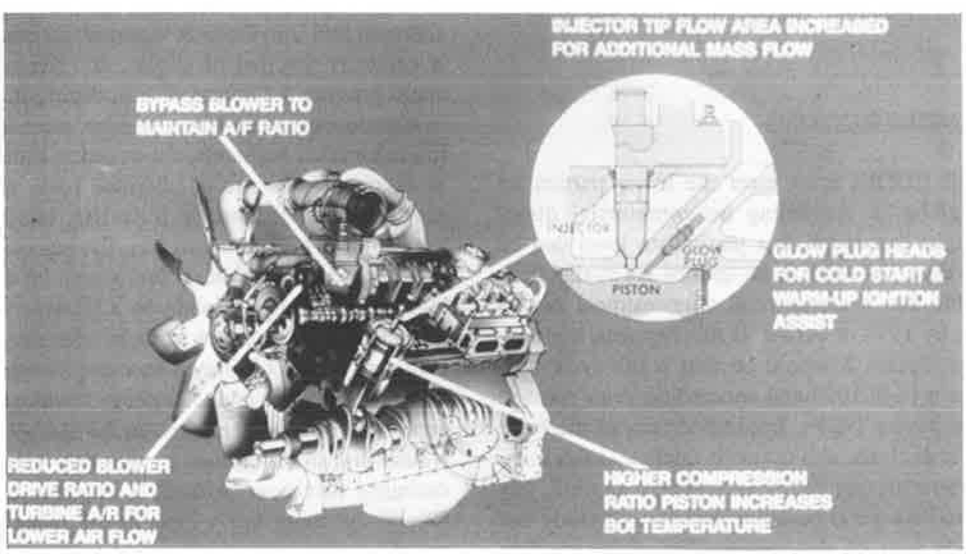

FIGURE 1 Engine modifications necessary for methanol operation.

TABLE 3 MODIFIED METHANOL ENGINE EMISSIONS AND FUEL CONSUMPTION

	Baseline	Modified	Diesel (1987)	Goal
NO_x	1.6–2.0	1.3	4.85	5.0
CO	6.4–7.0	7.2–7.3	1.2	15.5
HC	9.4–10.1	2.2–2.5	0.6	1.3
Particulates	0.23–0.24	0.056	0.32	0.1
Volatile fraction of particulates	–0.21–0.23	0.051	–0.08–0.12	
Aldehydes	0.4			0.1
Idle aldehydes (g/min)	0.5–0.14			0.05
Idle CO (%)	0.4			0.05
Cycle BSFC (lb/bhp-hr)	1.037–1.050	0.968–0.977	0.448 0.958[a]	

NOTE: Units are grams per brake-horsepower-hour unless otherwise noted.
[a]Methanol equivalent.

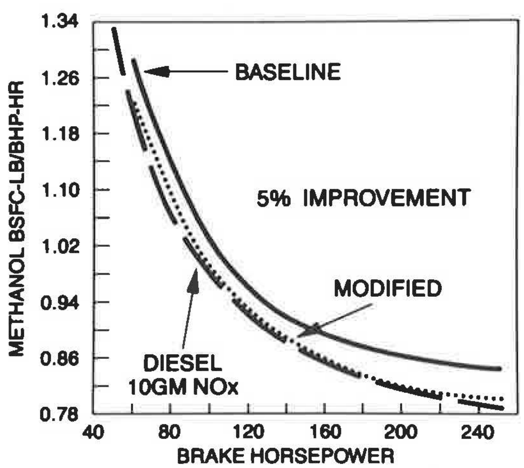

FIGURE 2 Methanol engine BSFC improvement at 2,100 rpm.

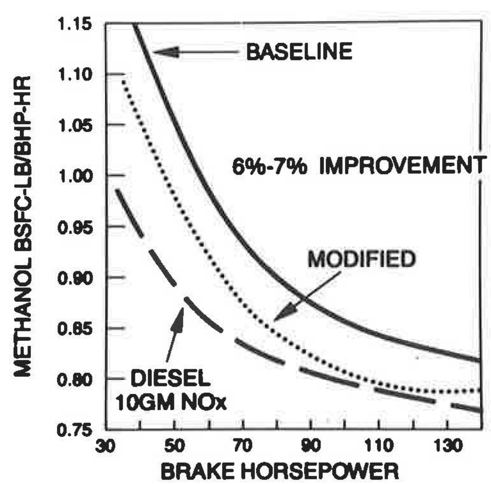

FIGURE 3 Methanol engine BSFC improvement at 1,000 rpm.

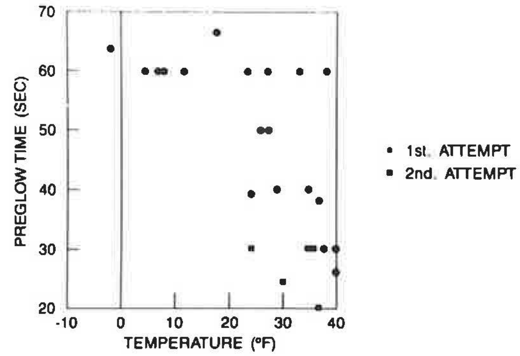

FIGURE 4 Methanol cold-start program (circles = first attempt; boxes = second attempt).

study to establish what aldehyde levels are acceptable in the environment. As Figures 2 and 3 show, the modified 6V-92TA methanol engine is now approaching the brake specific energy consumption of an equivalent diesel engine. Improvements in the brake specific fuel consumption (BSFC) of the modified engine range from 5 to 7 percent at various speeds and loads. More improvement is necessary at low speeds and light loads, and the effort is continuing to accomplish this. (At the time this paper was submitted, further development had resulted in meeting all program emission targets without aftertreatment.)

Cold-start data are shown in Figure 4. The goal for the urban bus engine in the EPA agreement was set equivalent to a diesel. This was interpreted to be a start at 30°F with 1 min of glow plug "preglow" and less than 30 sec of cranking. As Figure 4 shows, this goal was exceeded by starting at lower temperatures, even below 0°F, and at preglow times as short as 40 sec.

Another business aspect of this technology is that it could be applied to autoignite other fuels, such as gasoline, jet petroleum, and ethanol (Figure 5). Althouth the 6V-92TA is not now a competitor where these fuels enjoy a significant market, this potential will be considered in making the business decision to produce this engine for commercial sale in 1991.

CONCLUSIONS

Detroit Diesel has committed to the development of commercial methanol technology for the 1991 urban bus market. The rationale for this decision is based on the following considerations.

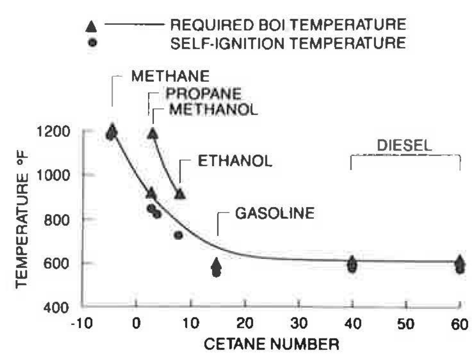

FIGURE 5 Minimum temperatures at beginning of injection (BOI).

1. Detroit Diesel's position as the leading supplier of bus engines in North America,
2. Status of Detroit Diesel methanol engine technology relative to that of the competition and the potential to meet the 1991 urban bus emission standards,
3. Transit authorities' reaction to the use of alternate fuels for bus fleets,
4. Federal and state support of alternate fuel programs to improve the environment, and
5. Need for a U.S. energy policy to encourage alternate fuel use and simultaneously develop an environmentally superior fuel.

All of the information needed to support a firm business decision is not currently available. Lacking are

1. Information on particulate NCPs for the HDDE;
2. Forecast of the availability of particulate traps for the HDDE;
3. A firm U.S. energy policy supporting alternate fuel use; and
4. Information about lower emission standards in the far term that could result in alternate fuel technology sales in specific markets (i.e., NO_x reductions for urban buses).

The technology Detroit Diesel is developing also could provide business opportunities where autoignition of other fuels (e.g., gasoline, jet petroleum, and ethanol) may prove advantageous to the customer.

Finally, unless something positive is done by the government to encourage the development of alternate fuel strategies for the United States, the future of alternate fuel engine technology will be quite unpredictable and dependent on politics and business decisions based on the information that is available when these decisions have to be made.

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